

Tucker et al. in U.S. Patent Nos. 4,193,397 and 4,258,711 (hereinafter "Tucker") disclose a dual reservoir implantable pump with an accumulator. Tucker further discloses a basal reservoir containing medication of a certain dosage and a smaller bolus reservoir containing high concentrate medication. The basal reservoir discharges medication to the patient at a specified rate. The basal reservoir discharges the high concentration of medication to a smaller accumulator and, at a specified time, the accumulator discharges the bolus dose into the basal medication discharge. However, Tucker's bolus dose is never mixed and diluted with the basal dose. The bolus dose is sent as a short 'burst' of medication at timed or triggered intervals. Additionally, both the basal and the bolus reservoirs contain medication that must be refilled by a doctor.

Thus, there is a need in the art for an implantable infusion device that mixes and dilutes a non-medication carrier with concentrated medication to reduce the size of the device. Additionally, diluting a concentrated medication with a carrier allows a patient to refill his/her own carrier reservoir multiple times before the medication reservoir requires refilling. This reduces the number of times a patient must visit a doctor to refill the medication reservoir.

SUMMARY OF THE INVENTION

An implantable infusion apparatus has a medication reservoir for storing a medication and a carrier reservoir for storing a carrier. The entire apparatus, including both reservoirs, is typically located in a single housing. The housing can be made of stainless steel, titanium, or any other strong corrosion resistant material. The reservoirs are typically made in the form of a bellows that expands and contracts with the discharge and replenishment of the

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drawings wherein like reference numerals in the various figures are utilized to designate like components, and wherein:

Figure 1 is a top view of the implantable infusion apparatus of the present invention;

Figure 2 is a partial cut-away view of the pump of along line 2 of Figure 3;

Figure 3 is a is a cross-section along line 3-3 of Figure 1;

Figure 4A is a top view of a microfluidic chip;

Figure 4B is a cross-sectional view along line 4B-4B of Figure 4A;

Figure 4C is a top view of an alternate embodiment of the microfluidic chip;

Figure 5 is a magnified view of one embodiment of the flow paths of the present invention;

Figure 6 is a magnified view of another flow path embodiment of the present invention;

Figure 7 is a magnified view of a restricted flow path embodiment of the present invention;

Figure 8 is a magnified view of the medication flow selector of the present invention;

Figure 9 is a magnified view of another flow path of the present invention;

Figure 10 is a schematic flow diagram illustrating a flow path of the present invention;

Figure 11 is a schematic flow diagram illustrating another flow path of the present invention;

orifice) can access each of the reservoirs. The above safeguards can allow a patient to safely refill carrier reservoir 106. The location of access ports 114, 116 with respect to pump housing 110 can also assist the patient/nurse/doctor in distinguishing between carrier access port 116 and medication access port 114. For example, medication access port 114 can be disposed in the center of housing 110 and carrier access port 116 can be disposed along housing's 110 perimeter.

A mixing chamber 124 is included to thoroughly mix and dilute medication 104 with carrier 108. Mixing chamber 124 must allow for full dilution and mixing of carrier 108 with medication 104 or the patient will receive an improper dose. One embodiment, as illustrated in Figures 4A and 4B, uses a microfluidic chip 128 to mix the two substances. Microfluidic chip 128 can have a medication input 130 and a carrier input 132 and capillary pathway 134 is configured in a serpentine pattern. The capillary pathway 134 can include convolutions in vertical and horizontal planes to the direction of flow. The convolutions act to allow medication 104 sufficient contact time with carrier 108 to allow for thorough mixing. Examples of microfluidic mixing chips include U.S. Patent Publication No. 2001/0048900, to Bardell et al.; U.S. Patent Publication No. 2003/0040105 to Sklar et al.; and U.S. Patent Publication No. 2003/0133358 to Karp. Other microfluidic mixing chips and mixing chambers to allow for thorough mixing are known to those of skill in the art.

One key to the mixing process is controlling the flow of both medication 104 and carrier 108 from reservoirs 102, 106 to mixing chamber 124. The flow rate can be controlled in numerous ways described below.

Referring now to Figures 5 through 9, a medication flow path 136 fluidly connects medication reservoir 102 to mixing chamber 124 and a carrier flow path 138 fluidly connects carrier reservoir 106 to mixing chamber 124. The flow paths can simply act as conduits between the reservoirs and the mixing chamber. Figure 5 illustrates one embodiment that alters the physical properties of medication flow path 136 so it is less restrictive than carrier flow path 138. Conversely, Figure 6 illustrates that medication flow path 136 is more restrictive than carrier flow path 138. The restrictive nature of a flow path is a factor in determining the flow rate of the fluid inside the path. For example, as illustrated in Figure 5, medication flow path 136 can be designed with a larger diameter A than a smaller diameter B of carrier flow path 138. Figure 6 illustrates that larger diameter A of carrier flow path 138 can be larger than smaller diameter B of medication flow path 136. The restrictions in the flow path can also be built into microfluidic chip 128, after inputs 130, 132, and before mixing chamber 124. Figure 4C illustrates a medication reduced diameter section 131, internal to microfluidic chip 128 that can act as the restriction to flow. Alternately, a carrier reduced diameter section 133 can also be disposed internal to microfluidic chip 128 to restrict the flow of carrier 108. Figure 4C illustrates both medication and carrier reduced diameter sections 131, 133, however, the reduced diameter sections can be used together or only one section can be restricted.

Additional embodiments, as illustrated in Figures 7 through 9, dispose either a medication flow restrictor 140 in medication flow path 136 to restrict the flow of medication 104 between medication reservoir 102 and mixing chamber 124; a carrier flow restrictor 142 in carrier flow path 138 to restrict the flow of carrier 108 between carrier reservoir 106 and

mixing chamber 124; or both flow restrictors 140, 142 can be included in the same apparatus, as illustrated in Figure 7. Flow restrictors 140, 142 can be physical changes to flow paths 136, 138 or microfluidic chips (not illustrated), depending on the configuration and flow rate required. As above, either flow restrictor 140, 142 can be more or less restrictive than the other.

Referring to Figure 8, a medication pump system 144 is used to discharge medication 104 to mixing chamber 124 and a carrier pump system 146 is used to discharge carrier 108 to mixing chamber 124. Medication pump system 144 has a medication discharge rate Q_m and carrier pump system 146 has a carrier discharge rate Q_c . As above, to properly control the mixing of medication 104 with carrier 108, the proper flows must be determined so the proper amount of medication 104 is diluted with the proper amount of carrier 108, depending on the dose to be administered to the patient. Discharge rates Q_m , Q_c can be configured in many ways, for example, medication discharge rate Q_m can equal carrier discharge rate Q_c and the flow can be restricted down stream of the pump by either flow paths 136, 138 or flow restrictors 140, 142. Alternately, medication discharge rate Q_m can be greater than or less than carrier discharge rate Q_c or any combination of flow paths 136, 138, flow restrictors 140, 142 and discharge rates Q_m , Q_c can be used to control the flow of both carrier 108 and medication 104.

Pump systems 144, 146 can be any pumping system known to those of skill in the art, including a power cell 113, 115 associated with the medication and the carrier reservoirs, respectively. Power cells 113, 115 can be a two-phase fluid power cell, where the fluid in the power cell vaporizes at physiological temperatures. The gas formed from the

vaporization of the fluid forces the reservoir to contract and expel the medication or carrier contained therein. When the reservoir is refilled, the reservoir is forced to expand against the vaporized liquid and the vaporized liquid condenses. Another power cell 113, 115 embodiment pressurizes the area surrounding medication and carrier reservoirs 102, 106 with a propellant, such as butane or Freon. The positive pressure of the propellant forces fluid out of reservoirs 102, 106 through one or both flow restrictors 140, 142 or microfluidic restrictors 131, 133. The combination of constant pressure and constant fluidic resistance due to the restrictors results in a constant discharge rates Q_m , Q_c . Additionally, a traditional battery operated system can be used to discharge medication 104 and carrier 108.

An outlet port 148 (Figures 1 and 10) is fluidly connected to mixing chamber 124 for discharging a diluted medication/carrier mixture to the patient. Outlet port 148 can be positioned and configured numerous ways to connect to a catheter (not illustrated) leading anywhere in the body.

The embodiment of implantable infusion apparatus 100 shown in Fig. 10 further includes a bolus port 150 disposed between mixing chamber 124 and outlet port 148. Bolus port 150 allows a doctor to introduce a bolus dose into apparatus 100, after medication 104 and carrier 108 have been mixed, but prior to the diluted mixture being discharged from apparatus 100. Bolus port 150 can be covered by a bolus compound septum 151 (Fig. 1) made of similar material to the septa described above. Additionally, bolus port 150 can be accessed from a common access port shared with the reservoirs and configured for another type of needle.

Referring now to Figure 9, another embodiment of an implantable infusion apparatus 100 is illustrated. Figure 9 illustrates an electronically controlled medication flow

selector 152 disposed in medication flow path 136 for controlling a selected medication discharge rate Q_m s of medication 106 to mixing chamber 124. Using medication flow selector 152, a doctor can alter the dosage of medication a patient receives without completely draining medication 104 from medication reservoir 102 and replacing it with a higher or lower concentration of medication 104. By altering the flow, a doctor can control how much medication 104 is mixed with carrier 108, and thus control the dosage. Another embodiment utilizes a carrier flow selector 154 disposed in carrier flow path 138 for controlling a selected carrier discharge rate Q_c s of carrier 108 to mixing chamber 124. Controlling the discharge rate of the carrier also affects the dosage. Both medication flow selector 152 and carrier flow selector 154 can be made of a valve 156 or a pump 158 (Figs. 8 and 9). An electronic device, such as a timer or a remote control, can control either valve 156 or pump 158. Flow selector 152 can be set to increase or decrease the amount of medication 104 that enters mixing chamber 124 based on a preset time. Additionally, telemetric remote controls can alter the programming of flow selectors 152, 154 through the skin of the patient. All of the other elements of the implantable infusion apparatus containing medication flow selector 152 are similar to the elements described in the above embodiments. Thus, embodiments of implantable infusion apparatus 100 include constant flow, wherein the flow rates of both the medication and the carrier are fixed prior to implanting the infusion apparatus into the patient; programmable flow, wherein the infusion apparatus contains electronics that are programmed to alter the flow of the medication and/or the carrier to vary the dosage to the patient at different times; and adjustable flow models that provide a constant flow of the medication and

carrier but the medication and/or carrier flow rate can be adjusted by a doctor to alter the flow rate of the constant flow.

Figures 10 and 11 are schematic diagrams illustrating typical embodiments for the present invention. Figure 10 schematically illustrates medication access port 114 in-line with medication reservoir 102. Medication flow path 136 fluidly connects medication reservoir 102 to mixing chamber 124 via medication flow restrictor 140. Carrier access port 116 is fluidly connected to carrier reservoir 106 and carrier flow path 138 fluidly connects carrier reservoir 106 to mixing chamber 124 via carrier flow restrictor 142. Further, bolus port 150 is disposed in the flow path between mixing chamber 124 and outlet 148 to permit the injection of a bolus dose. Figure 11 illustrates another embodiment wherein medication flow selector 154 is located in the flow path between medication flow restrictor 140 and mixing chamber 124 to allow additional control of medication discharge rate Q_m .

Figure 12 illustrates a method of infusing medication including storing a medication in a medication reservoir (step 200) and storing a carrier in a carrier reservoir (step 202). The carrier reservoir is sized larger than the medication reservoir. Approximately simultaneously, the medication is discharged to a mixing chamber (step 204) and the carrier is discharged to the mixing chamber (step 206). Once in the mixing chamber, the medication is mixed with the carrier to dilute it (step 208); and then the diluted medication/carrier mixture is discharged (step 210). As an additional step, a bolus dosage may be introduced into the diluted medication/carrier mixture prior to discharging the diluted medication/carrier mixture (step 212).

Another embodiment can restrict the discharge of the medication (step 214), restrict the discharge of the carrier (step 216) or restrict both. When both the medication and the carrier are restricted, the discharge of the medication can be restricted more than the

discharge of the carrier (step 218) or the carrier can be more restricted than the discharge of the medication (step 220). Other embodiments restrict the discharge of both the medication and the carrier to a certain extent to provide a constant flow rate to counter the constant action of the pumping system.

Further, Figure 13 illustrates that the dilution step can include contacting the medication with the carrier in the mixing chamber (step 222); flowing the contacted medication/carrier mixture through a series of mixing elements (step 224); and delaying the discharging of the diluted medication/carrier mixture until the medication is diluted to the proper dosage (step 226). The mixing elements can be baffles, hydraulic turbulence, or other mixing elements found in microfluidic devices.

Figure 14 illustrates another embodiment that adds the step of controlling the discharge of the medication into the mixing chamber (step 228). The electronic flow selectors as described above can perform the step of controlling the discharge of the medication.

Thus, while there have been shown, described, and pointed out fundamental novel features of the invention as applied to a preferred embodiment thereof, it will be understood that various omissions, substitutions, and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art without departing from the spirit and scope of the invention. For example, it is expressly intended that all combinations of those elements and/or steps which perform substantially the same function, in substantially the same way, to achieve the same results are within the scope of the invention. Substitutions of elements from one described embodiment to another are also fully intended and contemplated. It is also to be understood that the drawings are not necessarily drawn to

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